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OPTIMUM ECONOMIC STOCKING FOR NORTHERN HARDWOODS

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INTRODUCTION

The northern hardwood forests of Michigan aggregating nearly five million acres represent one of the valuable natural resources of the State. Over 1.6 million acres are classed as saw timber (1). Considerable areas of this timber type are now being managed under the selection system of cutting. Timberland owners are faced with decisions on how much timber to carry as growing stock in order to derive the largest board-foot and dollar increment. Fifteen-year growth records on eight cuttings and a reserve area on the Upper Peninsula Experimental Forest at Dukes, Michigan, provide answers to some of these questions. These cuttings, carried out in cooperation with the Cleveland-Cliffs Iron Company, are described below:

EXPERIMENTAL CUTTINGS

1. 22-inch diameter limit - 1926.- - Most trees over 22 inches d.b.h. were cut as well as a few of the more defective smaller ones. The volume removed totaled 2,350 board feet per acre net, which, with cull included, represented 29 percent of the original gross volume. Utilization on this and other cuttings described was exceptionally close. High-grade trees were cut into sawlogs; lower-grade material went into mine timbers and tie cuts. Cull hardwood logs and limbwood down to 4 inches in diameter were marketed for chemical wood.

2. Overmature and defective No. 1 - 1927-28.- - Overmature and defective trees were marked regardless of size or position in the stand. The cut per acre was 4,900 board feet net, 62 percent of the gross volume being removed.

1/ Maintained at University Farm, St. Paul 1, Minnesota, in cooperation with the University of Minnesota.

2/ Paper delivered at Ann Arbor, Michigan, April 2, 1948, before the Michigan Academy of Science, Arts, and Letters.

3/ The valuation study reported in this paper was drawn from a thesis completed at the University of Michigan in 1946-47, under the guidance of D. M. Matthews, Professor of Forest Management.

3. 12-inch diameter limit - 1927-28.- - Trees in the 12-inch d.b.h. class and larger were marked, together with some smaller ones injured in logging or especially defective. The volume removed was 7,300 board feet net per acre which, together with cull, amounted to 90 percent of the gross volume. This operation was similar to commercial clear cuttings except for the close utilization practiced.

4. Clear cutting - 1927-28.- - Everything merchantable, even chemical wood down to 5 inches d.b.h., was cut. The volume removed per acre was 10,740 board feet net.

5. Heavy improvement - 1928.- - A moderate selection of overmature and defective trees regardless of size was made, removing a volume of 3,470 board feet net per acre. In this cutting 46 percent of the gross volume was removed.

6. Light improvement - 1928.- - A very light selection removed only the most decadent trees, irrespective of size. The volume removed was 1,570 board feet net per acre or 24 percent of the gross volume (including cull).

7. Seventy percent selection - 1930.- - Most overmature and defective trees were marked together with any trees over 17 inches d.b.h., unless their removal would leave a large opening in the stand. That greater emphasis was placed on spacing than on leaving good trees is indicated by comparatively heavy mortality following logging. The cut amounted to 3,500 board feet net per acre. Sixty-eight percent of the gross volume was removed.

8. Overmature and defective No. 2 - 1932-33.- - Again the overmature and defective trees, regardless of size or spacing, were marked for cutting. The cut per acre was 4,200 board feet net. This plus cull represented 59 percent of the gross volume.

9. Virgin forest reserve area - 1927.- - This reserve area of 9 acres is included in the present series to serve as a control. Since the whole experimental area was culled lightly for elm and basswood during the period 1906 and 1910, the name adopted for this unit is somewhat misleading. Still, it has been left in an undisturbed condition following the early cutting, and is fairly typical of the eight units just described. Its volume after 15 years was 10,130 board feet net.

The residual stands left following cutting ranged from no board-foot volume in the case of the clear cutting to 7,890 board feet net (81 square feet of basal area in trees 10 inches d.b.h. and larger) per acre on the light improvement unit and 9,290 board feet (118 square feet of basal area) on the reserve area (table 1).

GROWTH FOLLOWING CUTTING

Growth has been better on the overmature and defective cutting No. 2 than on any other unit in the series (table 2). On this area the gross average

Table 1.--Residual stand per acre[1/]

Unit	Residual stand	
	Volume[2/]	Basal area
	Bd. ft.	Sq. ft.
Clear cutting, 1927-28[3/]	0	0
12-inch diameter limit, 1927-28	410	16
Overmature and defective No. 1, 1927-28	3,540	43
70-percent selection, 1930	3,200	43
Heavy improvement, 1928	5,490	58
Overmature and defective No. 2, 1932-33	5,500	62
Light improvement, 1928	7,890	81
22-inch diameter limit, 1926	7,360	84
Virgin forest reserve area, 1927[4/]	9,290	118

1/ Based on 20 acres on sample plots. Includes trees 10 inches d.b.h. and larger.
2/ Scribner log rule, net volume after deduction for cull.
3/ Cut winter 1927-28.
4/ Year of plot establishment.

Table 2.--Average annual growth per acre1/

Unit	Gross annual growth2/			Net annual growth3/
	5-year average	10-year average	15-year average	15-year average
	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.
Clear cutting	0	0	7	6
12-inch diameter limit	98	98	161	127
Overmature and defective No. 1	165	188	236	184
70-percent selection	112	183	222	176
Heavy improvement	163	171	218	165
Overmature and defective No. 2	255	296	4/ 296	4/ 253
Light improvement	235	256	255	194
22-inch diameter limit	245	228	236	189
Virgin forest reserve area	191	79	89	56

1/ Based on 20 acres of sample plots. Scribner log rule employed.
2/ Mortality deducted. No deduction for defect.
3/ Deductions made for mortality and defect.
4/ Ten-year average. Fifteen-year data not yet available.

annual growth was 296 board feet per acre, the net growth 253 board feet. By way of contrast, the clear cutting has only averaged 6 board feet net and the 12-inch diameter limit cutting 127 board feet net.

Net average annual growth has been related to residual volume and basal area (5). It was found that maximum growth in board feet occurred where a residual stocking of 6.0 M board feet or 64 square feet of basal area in trees 10 inches d.b.h. and larger was left after logging. In the curved values, annual growth exceeded 200 board feet in all cases where the residual growing stock was from 4.5 to 7.0 M board feet (52 to 74 square feet of basal area) per acre.

Stocking for maximum board-foot growth does not in itself satisfy all forest owners and managers. The interest return on the forest investment, as represented by land value, residual growing stock, and capitalized current charges, such as taxes, is generally an important consideration. In many cases it may well be the limiting factor. It seems likely that private timberland owners, who control by far the greater portion of the remaining merchantable hardwood volumes in Michigan, will, in the main, stay in the timber-growing business or liquidate solely on the basis of the financial soundness or unsoundness of the venture.

The discussion which follows is an attempt to evaluate the same series of eight cuttings and a reserve area from this latter point of view. Again, the growing stock needed following cutting will be defined in terms of volume and basal area, but this time in order to provide maximum return on the investment.

THE VALUATION STUDY

A consideration of values in northern hardwoods leads inevitably to grades. In this case the trees to be graded were still standing and their value had to be determined as accurately as possible by superficial examination.

The first phase of the valuation study, therefore, consisted of grading each log in each tree 10 inches d.b.h. and over on each sample plot on each cutting unit. The O.P.A. log-grading specifications in effect at the time (3) were adhered to strictly in the operation. Taper tables were used to advantage in making these estimates. When field work had been completed, the gross volume in each grade and the percentage of gross volume in each grade were computed for each unit.

The O.P.A. log ceiling prices effective November 29, 1945 (4) form the basis for all value comparisons in this paper. An allowance of $5.00 per M board feet for hauling was added to the O.P.A. log ceilings to establish f.o.b. mill prices. Other products were priced at the current rate f.o.b. mine or plant. By deducting direct logging costs--costs built up for the Dukes area by time studies over a period of years and adjusted to current economic conditions--a surplus value was derived for each product (table 3). (Surplus value equals mill or plant receipts minus direct logging costs.)

Table 3.--Derivation of surplus value of forest products

Item	Value or cost of product					
	Per M board feet				Per lin.ft.	Per cord
	Logs 1/			Chemical bolts	Mine timbers	Chemical wood
	No. 1	No. 2	No. 3			
	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars
Value f.o.b. mill	89.00	38.00	31.00	25.34	.0855	10.00
Direct logging cost	24.45	24.45	24.45	21.94	.0855	9.14
Surplus value	64.55	13.55	6.55	3.40	.0000	0.86

1/ It is recognized that the use of uniform logging costs tends to reduce the spread between log grades No. 1 and No. 3, since costs are usually somewhat greater for smaller and more defective logs. Refinement of cost figures to this extent was not deemed necessary for this analysis.

However, special direct logging costs were used for the 12-inch diameter limit and clear cutting units because all logs were small. On the 12-inch diameter limit cutting merchantable trees averaged less than 13 inches d.b.h. after 15 years, and a cost of $38.00 was employed. On the clear cutting the few logs present were of small mine timber size (2 bd. ft. per linear foot), so a cost of $42.75 was used. The surplus values shown in table 3 were reduced accordingly for these units.

The gross volumes by log grade mentioned previously were reduced by the percentage of cull currently present on each unit. In the case of mine timbers and chemical wood, no reduction was necessary because very little culling of these products is done by buyers. The merchantable volume of each product was then multiplied by its surplus value. To these figures were added the value of chemical wood in tops and trees under 10 inches d.b.h. computed from permanent sample plot records for the cutting units in question. Thus, a surplus value per acre was determined for the stand on each unit 15 years after cutting.

In the same manner a surplus value was computed for 15 years' accumulated growth, after first applying the grade proportions described earlier to measured 15-year gross growth volumes. By deducting this surplus value of 15 years' growth from the surplus value of the stand after 15 years, the surplus value under identical market conditions of the residual stand on each cutting unit at the time of logging was derived.

Finally, fixed per-acre costs of $7.50 were deducted from each unit surplus value in order to determine the recovery value of the residual stand left on each unit (table 4). Included as fixed costs were such items as roads, other improvements, cruising, and the like. They might vary somewhat between cases, but detailed figures would change the picture very little. Recovery value, the difference between the value of the products f.o.b. mine, plant, or mill, and the actual cost to put them there, rather than stumpage value, was employed in this report. This was done to avoid the necessity of assigning an arbitrary percentage of margin, usually expressed as percentage of operating costs. Since recovery value was used consistently in growth and residual stand valuations alike, this disregard of margin should not influence earned interest rates significantly.

Cutting cycles of 5, 10, 15 and 20 years are considered in the analysis. Therefore, the periodic recovery value of 5, 10, 15 and 20 years' growth for each unit was a necessary prerequisite to any interest calculations. Computing of the surplus value for 15 years' accumulated growth has already been described. The surplus value for 5, 10, and 20 years' growth was determined by the same procedure. Then, fixed per-acre cost of $7.50, considered to be continuing expenses incurred once each cycle at time of logging, were deducted in each instance to give the recovery values desired (table 4).

Annual tax payments of $0.0375 to $0.50 per acre (table 4), realistic for forest properties of this type and condition in Marquette and Alger counties, Michigan were used in the interest calculations. A cut-over hardwood land value of $2.50 per acre, equally realistic for the vicinity of Dukes, was employed.

Table 4.--Values per acre under sustained yield

Unit	Recovery value[1]					Annual tax
	Residual volume	Periodic growth[2]				
		5 years	10 years	15 years	20 years[3]	
	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars
Clear cutting	0.00	0.00	0.00	0.00	0.00	0.0375
12-inch diameter limit	0.00	0.00	0.00	0.00	0.00	0.05
Overmature and defective No. 1	70.69	8.48	28.30	57.99	79.82	0.30
70-percent selection	61.75	2.35	24.33	49.82	68.92	0.30
Heavy improvement	132.99	8.94	27.21	58.58	80.62	0.40
Overmature and defective No. 2	127.75	20.70	57.39[4]	89.83[4]	122.28	0.40
Light improvement	173.91	13.78	39.36	61.83	84.94	0.40
22-inch diameter limit	173.13	17.53	39.22	65.76	90.19	0.40
Virgin forest reserve area	204.70	6.23	3.95	12.38	19.00	0.50

1/ Based on 20 acres of sample plots
2/ Only periodic net growth removed in cutting.
3/ Based on 15-year growth averages.
4/ Based on 10-year growth averages.

Compound and simple interest earned for 5-, 10-, 15-, and 20-year periods (cutting cycles) under sustained yield were computed for each unit (table 5) by the use of standard formulas 4/ (2).

It is felt that the interest earned rates calculated in this study are conservative. Growth accrued on the perimeter of the trees where the lumber grade is highest, yet the grade proportion for growth was determined on the basis of the proportion of grades in the total stands. Then, too, no advantage was taken of improved market conditions, although there has been a marked increase in recovery value over the years. Finally, no allowance was made for the further cull reduction which should result from good management practices.

Differences between compound and simple interest rates appear small because of the low rates and short periods involved.

STOCKING FOR MAXIMUM RETURN ON INVESTMENT

In order to round out the relationship between residual volume and residual basal area to interest earned, compound and simple interest rates with 5-, 10-, 15-, and 20-year cutting cycle (table 5) were, in turn, curved over residual volumes (table 1). From these curves compound and simple interest rates earned on a series of residual volumes ranging from 0 to 9.5 M board feet were read (table 6).

Summed up briefly, residual volumes of from 3.5 to 4.5 M board feet (44 to 52 square feet of basal area) in trees 10 inches d.b.h. and up per acre, inclusive, with a 10-year cutting cycle; residual volumes of from 2.5 to 5.5 M board feet (36 to 60 square feet of basal area) with a 15-year cycle; and residual volumes of from 3.0 to 5.0 M board feet (40 to 56 square feet of basal area) with a 20-year cycle all earned at least 3.0 percent compound interest. A residual volume of 3.5 M board feet (44 square feet of basal area) per acre with a 15-year cutting cycle was the best investment, earning at the rate of 3.6 percent compound interest. A cutting cycle of 15 years held slight superiority over 5, 10, and 20 years for most stockings.

4/ Compound interest was computed by the following formula:

$$1.0p^t - 1 = \frac{a}{Co}$$

where, a = recovery value of periodic growth (table 4)
Co = residual recovery value of stand (table 4) plus cutover land value ($2.50) plus annual tax payment (table 4) capitalized at (divided by) an interest rate giving the same value to p in the formula above.
t = interval between payments.
p = interest rate.

Simple interest was derived by this formula:

$$t \times .0p = \frac{a}{Co}$$

Table 5.--Interest earned under sustained yield[1/]

Unit	Interest earned							
	5-year cycle		10-year cyle		15-year cycle		20-year cycle	
	Com-pound:	Simple	Com-pound:	Simple	Com-pound:	Simple	Com-pound:	Simple
	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Clear cutting	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12-inch diameter limit	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Overmature and defective No. 1	1.8	1.9	3.0	3.4	3.6	4.7	3.5	4.9
70-percent selection	0.3	0.3	2.9	3.3	3.5	4.6	3.4	4.7
Heavy improvement	1.0	1.0	1.6	1.7	2.2	2.5	2.1	2.6
Overmature and defective No. 2	2.7	2.9	3.5	4.0	3.3	4.2	3.1	4.3
Light improvement	1.3	1.3	1.8	2.0	1.8	2.1	1.8	2.1
22-inch diameter limit	1.7	1.8	1.8	2.0	2.0	2.2	1.9	2.3
Virgin forest reserve area	0.4	0.4	0.1	0.1	0.2	0.2	0.2	0.2

1/ Based on 20 acres of sample plots.

Table 6.--Return on investment from sustained yield with different residual volumes and cutting cycles

Residual stand per acre 1/		Interest earned							
		5-yr. cycle		10-yr. cycle		15-yr. cycle		20-yr. cycle	
Volume 2/	Basal area	Compound	Simple	Compound	Simple	Compound	Simple	Compound	Simple
M bd. ft.	Sq. ft.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0	22	0.1	0.1	0.4	0.4	0.5	0.5	0.4	0.4
1.5	28	0.2	0.2	1.0	1.1	1.4	1.5	1.2	1.3
2.0	32	0.4	0.4	1.7	2.0	2.4	2.6	2.2	2.5
2.5	36	0.6	0.6	2.3	2.8	3.1	3.7	2.9	3.8
3.0	40	0.8	0.9	2.8	3.2	3.5	4.5	3.3	4.6
3.5	44	1.1	1.2	3.0	3.4	3.6	4.7	3.5	4.8
4.0	48	1.4	1.4	3.1	3.4	3.5	4.6	3.4	4.7
4.5	52	1.6	1.6	3.0	3.4	3.4	4.3	3.3	4.4
5.0	56	1.7	1.8	2.9	3.2	3.2	4.0	3.1	4.1
5.5	60	1.9	2.0	2.8	3.1	3.0	3.7	2.9	3.8
6.0	64	1.9	2.0	2.5	2.9	2.8	3.3	2.6	3.4
6.5	68	1.9	2.0	2.3	2.6	2.5	2.9	2.3	2.9
7.0	74	1.8	1.8	2.0	2.2	2.1	2.4	2.0	2.5
7.5	80	1.6	1.6	1.7	1.9	1.8	2.0	1.6	2.0
8.0	88	1.3	1.3	1.3	1.4	1.4	1.5	1.3	1.5
8.5	99	1.0	1.0	0.9	1.0	0.9	1.0	0.9	1.0
9.0	110	0.6	0.6	0.4	0.4	0.5	0.5	0.5	0.5
9.5	124	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0

1/ Trees 10 inches d.b.h. and larger.
2/ Scribner log rule.

RELATIONSHIP TO STOCKING FOR MAXIMUM BOARD-FOOT GROWTH

As pointed out earlier where the residual growing stock ranged from 4.5 to 7.0 M board feet (52 to 74 square feet of basal area) in trees 10 inches d.b.h. and larger per acre, annual growth exceeded 200 board feet. Maximum growth occurred at 6.0 M board feet or 64 square feet of basal area (5).

It is quite evident, then, that financial considerations operate to reduce the volume retained as growing stock. However, it must be remembered that continuous production of saw timber by the selection system will depend upon a full distribution of size classes, and the retention of enough merchantable trees at all times to provide for future economic cutting operations. This adequate distribution would seem to be easier to maintain where stocking is never below 6.0 M board feet per acre than say 3.5 M board feet, the optimum for interest earned.

It will be noted that there is a certain amount of overlap between these two conceptions of stocking. Stockings of from 4.5 M board feet to 5.5 M board feet per acre are common ground. It should, therefore, be possible to stock both for good growth and for good interest return.

Holding in the neighborhood of 5.5 M board feet (60 square feet of basal area) in trees 10 inches d.b.h. and up per acre will be close to the growth optimum for site similar to those on the Upper Peninsula Experimental Forest. This volume will also return 3.0 percent compound interest if a 15-year cutting cycle is employed (table 6). It should, as well, allow for sufficient trees to provide adequate size distribution and to cover normal mortality losses.

Public forest and certain private holdings may be managed with more of an eye to maximum growth rather than for highest interest return. In the case of the experimental area under discussion, up to 7.0 M board feet (74 square feet of basal area) per acre could be held. To retain stockings of more than this figure following cutting would not be justified either by growth or by interest return on the investment.

It seems advisable to point out further that these experiments were conducted in upland hardwoods of good productivity. The results reported should not be applied indiscriminately to extensive forest properties where variations in type and condition exist.

SUMMARY

Residual stockings on eight cuttings and a reserve area in the northern hardwood type in Upper Michigan have been analyzed from the point of view of interest earned on the forest investment. Taxes, land value, and cost of logging as well as growth, mortality, defect, and grade were taken into account in making the appraisal.

A residual volume following cutting of 3.5 M board feet (44 square feet of basal area) per acre in trees 10 inches d.b.h. and larger with a 15-year cutting cyle was the best investment, earning 3.6 percent compound interest. Residual volumes of 2.5 to 5.5 M board feet (36 to 60

square feet of basal area) per acre earned 3.0 percent compound interest or better. A cutting cycle of 15 years appeared slightly superior to 5, 10, and 20 years for most stockings.

These stockings are somewhat lighter than would be retained for maximum board-foot growth. Still there is some overlap and a stocking of about 5.5 M board feet (60 square feet of basal area) per acre should provide good growth and also a satisfactory return on the investment.

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